FATIGUE LIFE BEHAVIOUR OF FIBERGLASS REINFORCED COMPOSITES SUBJECTED TO CONSTANT AND VARIABLE AMPLITUDE LOADINGS

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A thesis submitted
in fulfilment of the requirement for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled "Fatigue Life Behaviour of Fiberglass Reinforced Composites Subjected to Constant and Variable Amplitude Loadings" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………..

Name : Roy Hanson Anak Jimit

Date : ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : ………………………………..

Supervisor Name : Dr. Kamarul Ariffin Bin Zakaria

Date : ………………………………..

DEDICATION

To my beloved family especially my wife; Jacquelyn Liang, my parents; Mr Jimit Maying and Mrs Beremas Gani, and my siblings; Nancy Jimit and David Jimit.

ABSTRACT

This study focuses on the variable amplitude loadings effect on fatigue life behaviour of Fiberglass-reinforced composite (FGRC). Unidirectional fiberglass-reinforced composite were used as subjects of this study due to their wide application in automotive and engineering components. The manufacturing some of automotive parts are made from fiberglass including the interior or exterior panels, dashboard components, seats, spoilers, sills panel and body structures. The study of fatigue life under variable amplitude loadings (VAL) is an important subject as most of engineering components are subject to stresses which vary with time. Fatigue failure usually occurred without warning. Therefore, the needs of more predictive tools and understanding on the integrity of this material could help to produce a more reliable engineering material in the future. The main objective of this study is to investigate the effect of overloads (OL) and underloads (UL) toward the fatigue life behaviour of the FGRC test coupon of different orientation which are [0/90]° and [±45]° orientations and chopped strand mat (CSM). Firstly, a static finite element analysis was performed to determine the most critical area of the FGRC test coupon. Next, the critical stress value was recorded from the tensile test on the test coupon according to the standard in ASTM D3039. Tensile test is carried out to determine the mechanical properties of the FGRC. The results showed that the Ultimate Tensile Stress (UTS) of FGRC is the highest in [0/90]° orientations compared to [±45]° orientation and CSM. After that the fatigue tests were carried out at room temperature in accordance to the ASTM D3479 for both Constant Amplitude Loadings (CAL) and Variable Amplitude Loadings (VAL). Secondly, the CAL fatigue test is carried out for all the orientations including CSM. Results showed [0/90]° orientations have the highest fatigue life cycle. Thirdly, OL and UL effects were generated from the CAL fatigue test results. Results showed that UL effect deteriorate the fatigue life behaviour of FGRC from 1.4% to 14% decrement from the actual value when being compared to result in CAL due to acceleration effect in fatigue crack growth rate while the effect of OL increase the fatigue life behaviour of FGRC by minimum 5% from the actual value due to retardation effect in the fatigue crack growth rate.

ABSTRAK

Kajian ini memfokuskan kesan pembebanan pelbagai amplitud ke atas perilaku hayat lesu komposit gentian kaca bertetulang (FGRC). Komposit gentian kaca bertetulang digunakan sebagai bahan kajian ini kerana penggunaannya yang meluas dalam komponen automotif dan kejuruteraan. Antara bahagian automotif yang diperbuat daripada gentian kaca termasuk yang digunakan dalam pembuatan panel dalaman atau luaran, komponen papan pemuka, tempat duduk, panel ceruk dan struktur badan. Pengkajian hayat lesu di bawah pembebanan pelbagai amplitud merupakan subjek yang penting kerana sebahagian besar komponen kejuruteraan dikenakan tegasan yang berubah-ubah dengan masa. Kegagalan lesu biasanya berlaku tanpa amaran. Oleh itu, perlunya lebih banyak kaedah ramalan dan pemahaman tentang integriti bahan ini akan membantu menghasilkan bahan kejuruteraan yang lebih dipercayai dan mapan pada masa hadapan. Objektif utama kajian ini adalah untuk mengkaji kesan beban lebih (OL) dan beban kurang (UL) ke atas perilaku hayat lesu sesebuah sampel ujian FGRC bagi orientasi yang berbeza iaitu orientasi [0/90] ° dan [± 45] ° dan gentian yang dicincang (CSM). Pertama, analisis unsur terhingga secara statik dilakukan untuk menentukan kawasan paling kritikal pada kupon ujian tersebut. Seterusnya, nilai tegasan kritikal dicatatkan dari ujian tegangan pada kupon ujian mengikut piawaian dalam ASTM D3039. Ujian tegangan dilakukan untuk menentukan sifat mekanik FGRC. Keputusan menunjukkan bahawa kekuatan tegangan muktamad (UTS) FGRC adalah yang tertinggi dalam orientasi [0/90] berbanding dengan orientasi [± 45] ° dan CSM. Selepas itu, ujian lesu dilakukan pada suhu bilik mengikut ASTM D3479 untuk kedua-dua pembebanan amplitud-malar (CAL) dan pembebanan pelbagai amplitud (VAL). Kedua, ujikaji lesu CAL dijalankan untuk semua orientasi termasuk CSM. Keputusan menunjukkan orientasi [0/90] mempunyai kitaran hayat lesu tertinggi. Ketiga, kesan OL dan UL dijana daripada keputusan ujikaji lesu CAL. Keputusan menunjukkan kesan UL terhadap perilaku jangka hayat lesu merosot daripada 1.4% hingga 14% daripada nilai sebenar apabila dibandingkan dengan keputusan CAL disebabkan kesan percepatan terhadap kadar retak lesu manakala kesan OL terhadap perilaku jangka hayat lesu meningkat sekurang-kurangnya 5% daripada nilai sebenar disebabkan kesan rencatan terhadap kadar retak lesu..

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σ_a	-	Stress amplitude
σ_r	-	Stress range
σ_{max}	-	Stress maximum
σ_{min}	-	Stress minimum
R	-	Stress ratio
N_D	-	Number of delay cycle
N_{D1}	-	Real number of delay cycle
a_D	-	Delay distance
σ_f	-	Fatigue strength coefficient
$2Nf$	-	Sum of the reverse cycle
b	-	Basquin's exponent
E_1	-	Longitudinal modulus
E_2	-	Transverse modulus
V_{12}	-	Major Poisson's ratio
G_{12}	-	X-Y in-plane modulus
G_{13}	-	X-Z in-plane modulus
G_{23}	-	Y-Z in-plane modulus
FV_f	-	Fiber volume fraction
ρ_f	-	Fiber density
ρ_m	-	Matrix density
T_d	-	Theoretical density
FW_f	-	Fiber weight fraction
$V\%$	-	Void content
M_d	-	Measured density
E	-	Modulus of elasticity

ε_{ult}	-	Ultimate tensile strain
N_f	-	Number of cycle to failure

LIST OF ABBREVIATIONS

ASTM	-	American Standard Testing Method
CAL	-	Constant Amplitude Loading
CGMC	-	Carbon and Graphite Matrix Composite
CMC	-	Ceramic Matrix Composite
CSM	-	Chopped Strand Mat
EU	-	European Union
FCG	-	Fatigue Crack Growth
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
FGRC	-	Fiberglass Reinforced Composite
FRC	-	Fiber Reinforced Composite
FRP	-	Fiber Reinforced Polymer
HDT	-	Heat Deflection Temperature
MMC	-	Metal Matrix Composite
OL	-	Overload
OLR	-	Over Load Ratio

PMC	-	Polymer Matrix Composite
RTM	-	Resin Transfer Molding
S-N	-	Stress-Life
UL	-	Underload
ULR	-	Under Load Ratio
UTS	-	Ultimate Tensile Strength
VAL	-	Variable Amplitude Loading
WHO	-	World Health Organization

LIST OF PUBLICATIONS

Journals

1. R. H. Jimit, K. A. Zakaria, O. Bapokutty and S. D. Malingam, 2018. *Tensile and fatigue behaviour of glass fiber reinforced polyester composites.* International Journal of Engineering and Technology (IJET), 7(3.17), pp. 25-27.

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Research Symposium In Mechanical Engineering 2016 (PRISME), Melaka, 5 January 2016.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Recently, public awareness on the environment and safety issues is continuously increasing throughout the world. Environmental problems such as air pollution and water pollution have become a serious problem not only in developed country but also developing country. This problem can endanger animals, plants as well as deteriorate health of human beings. According to World Health Organization (WHO), almost seven million people worldwide died in year 2012 due to air pollution (WHO, 2014). Combustion of vehicle fuel had been identified as the main factor which causes air pollution. EU has set the aim to decrease the emissions with 20 % compared to today to 2020 (Scania AB, 2011). One way to reduce fuel consumption is weight reduction of the body structure of vehicle. Therefore, the applications of composite material become an interest and hot topic among the researcher and public as it can reduce vehicle weight.

Composite consists of two or more microscopically combined materials to produce a new and better quality material. From the production of composite , the mechanical properties of the material such as strength, stiffness, corrosion resistance, wear resistance, fatigue strength, temperature-dependent behaviour and thermal conductivity can be improved (Banakar et al., 2012; Mukul and Sachin, 2012 cited in Banakar et al., 2017). One of the most significant type of composite is fiber-reinforced composite (FRC) that mostly used as an engineering structure and component in industrial. FRC consists of fibers of high strength and modulus embedded in or bonded to a matrix with boundaries between them. In this form, both fibers and matrix resin maintain their physical and